The University of Chicago
FOUNDED BY JOHN D. ROCKEFELLER

# SPECTROSCOPIC STUDIES ON HYDROGEN

## PART IA.

## THE EFFECT OF TEMPERATURE UPON THE HYDROGEN SPECTRUM AS PRODUCED BY ALTERNATING CURRENT

A DISSERTATION

SUBMITTED TO THE FACULTY OF THE OGDEN GRADUATE SCHOOL OF SCIENCE IN CANDIDACY FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

(DEPARTMENT OF PHYSICS)

BY

HARVEY BRACE LEMON

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By HARVEY BRACE LEMON

*Introduction.*—The question as to whether any analogy exists between the behavior of line spectra and of continuous spectra, and if so, what are its limitations, has long been a mooted one in spectroscopy. For continuous spectra, excited solely by temperature, we have had a firm theoretical basis developed by Boltzmann, Wien, Planck, and others, upon which to work. Experiment has in a remarkable manner confirmed the deductions of theory. In the case of line spectra of gases and vapors, however, the situation is far otherwise. Until we have a more definite picture of what the emitting mechanism is, theory has no foundation upon which to build. To picture the mechanism we must have first of all agreement as to the phenomena it produces. As yet we have not even succeeded in this very preliminary requisite. We are not agreed upon the data at hand, still less are we prepared for their interpretation. With the large number of variables associated in the production of spectra of this type, it is not surprising that our data are as yet fragmentary and deal with very special cases. The importance of correlating these, however, in the hope that they may fit together and give us some clue to the mechanism beneath can not be overestimated. It may be that spectroscopic data alone will be insufficient—that perhaps a study of the ionization processes taking place simultaneously with the production of light may be necessary. The general aim of the present work will be confined to an attempt to bring the spectroscopic data available into concordance.

Because of the apparent simplicity of at least one portion of its spectrum and on account of its predominant character in the spectra of many stars, hydrogen has been one of the most widely studied elements, especially as to the question of analogy between the behavior of its series spectrum and that of continuous spectra. Kayser[1] and Langenbach[2] in 1903 attempting this parallel between

[1] "Zur Temperaturbestimmung strahlender Gase," *Boltzmann Festschrift*, p. 38 (July 1903), Barth, Leipzig, 1904.

[2] "Ueber Intensitätsverteilung in Linienspectren," *Annalen der Physik*, **10**, 789, 1903.

continuous and discontinuous spectra believed they detected a shift in the energy maximum of emission toward the violet with increased electrical excitation. The order of magnitude of this effect was considerable. If the same effect had been observed in the temperature radiation of a black body it would have corresponded to a rise in temperature of the radiator from 2200 to 2760 degrees absolute. This does not say, however, that such was the temperature of the hydrogen. In fact, looked at from other angles there seems to be little ground for any analogy whatever, for the comparison is between a so-called "luminescent" radiation excited solely by an electrical discharge and one whose origin lies in temperature alone. Kayser's and Langenbach's results have meaning only as showing a relation between the radiation and the intensity of excitation. Moreover, Nutting and Tugman[1] studying the effect of electrical conditions, primarily current and pressure, upon the hydrogen radiation, reach conclusions not in accordance with those of Kayser and Langenbach. Jungjohann[2] on the other hand agrees qualitatively with Langenbach as to the effect of pressure on the energy-maximum shift but disagrees with Kayser as to the correspondence of this shift with that of a black body. All of these experiments have been carefully conducted, but the methods used have been widely divergent, especially as to the mode of excitation employed; and to this and to one other cause about to be mentioned must the disagreements be ascribed.

*Continuous background.*—In making photometric measures on the spectrum of hydrogen one very important factor seems to have been universally overlooked, and it may be the neglect of this factor, more than experimental differences in method, has been the greatest cause of the discrepancies among workers in this field. This factor is the continuous spectrum of hydrogen. There are present in all ordinary forms of vacuum tubes filled with pure hydrogen three spectra—the series line spectrum, the compound line spectrum, and the continuous spectrum. The last, very faint

[1] "The Intensities of Some Hydrogen, Argon, and Helium Lines in Relation to Current and Pressure," *Bulletin Bureau of Standards*, **7**, 49, 1911.

[2] "Ueber Emission und Absorption leuchtender Gase bei hohen Stromdichten unter Verwendung von Gleichstrom," *Zeit. f. Wiss. Photog.*, **9**, 84, 105, 141, 1910.

in the red, becomes, even at low pressures (1–3 mm), quite strong in the blue and very marked in the violet. Obviously when examined under the low dispersion of a spectrophotometer it doubtless consists of a mixture of true continuous background and unresolved compound line spectrum. In any case measures made on the series lines $H\beta$, $H\gamma$, and $H\delta$, etc., will be largely in error unless correction is made for this continuous background on which these lines appear. A glance at the following table will show clearly the magnitude of this correction.

TABLE I

MAGNITUDE OF THE BACKGROUND CORRECTION

| | $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\alpha_g$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|---|---|
| Uncorrected | .084 | .130 | .169 | .033 | .094 | .... | .... | .... |
| Corrected | .084 | .081 | .035 | .033 | .045 | .000 | .049 | .134 |

The figures represent the photometric intensities of the series lines $H\alpha$, $H\beta$, $H\gamma$, and of a group of secondary lines, $a$, in the red ($\lambda = .600–.603\ \mu$), $b$, in the blue ($\lambda = .492–.495\ \mu$), relative to the intensity of the corresponding portions of the spectrum of a Nernst glower. The gas was pure, under a pressure of .318 cm and was carrying a current of 6 milliamperes; the form of tubes and the apparatus is described fully below. The first line in the table gives the intensities as measured without any consideration being taken of the background. The second line shows that whereas the red lines $\alpha$ and $a$ are unchanged, owing to the absence of the background in the red, the blue lines have their intensity values changed by 40 to 50 per cent and the violet line by as much as 80 per cent. The intensity of the background immediately adjacent to the red side of the series lines, denoted in the table by $\alpha_g$, $\beta_g$, $\gamma_g$, is seen to rise very rapidly from zero in the red to a magnitude almost equal to that of $\gamma$ in the violet. At lower pressures the background is not so strong, at higher pressures it is much more marked, in fact, it becomes so strong that $H\gamma$ is seen with difficulty, if at all, on it. That so large a source of error in the intensities of the hydrogen lines should have been overlooked by previous workers seems very strange. However, none of them in any place makes mention of

observations on the continuous background or of any correction of the line intensities due to it. Plate VI, a reproduction of photographs of the spectra given by some of the hydrogen tubes used, shows clearly the magnitude of the continuous ground. *A* is taken with the large dispersion of a 2-meter focus, $3\frac{1}{4}$-inch concave grating ruled by Professor Michelson; *B* is taken with a small prism for the dispersion piece, and shows the effect of pressure in strengthening the background.

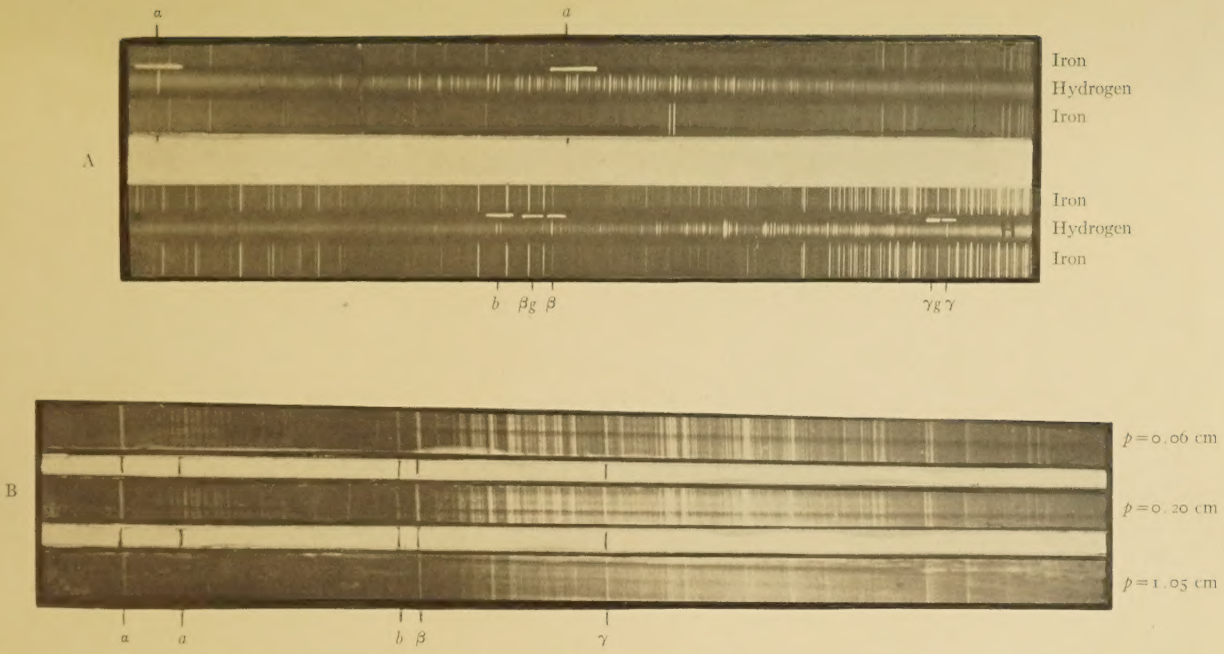
*Outline of experiments.*—The original aim of these experiments was an attempt to throw some light upon the open question as to the effect of temperature alone on the emission of hydrogen. The method was the very simple one of changing the temperature of the discharge tube through a large range and making photometric measures on the intensities of the various portions of the spectrum. Electrical conditions were of course to be held as nearly constant throughout as was possible. In the course of these first experiments there came to light the above-mentioned possible cause of the disagreement of previous workers on the question of the effect of electrical conditions, and the original aim of the undertaking has been broadened to a somewhat more extensive one. This will include the study of the effect of electrical conditions on the radiation of hydrogen, helium, and perhaps other elementary gases, as well as the effect of temperature alone.

## Part I*a*

### The effect of temperature upon the hydrogen spectrum as produced by alternating current

*Apparatus.*—The apparatus consisted of the hydrogen generator and purifier, the discharge tubes, the electrical exciting equipment, and the spectrophotometer. A general view is given in the photograph, Plate VII. Fig. 1 is a detail drawing of the hydrogen generating and purifying apparatus. It was made entirely of glass with a minimum number of stopcocks. The gas was generated by the electrolysis of a dilute solution of orthophosphoric acid in tube *A*. So prepared, it contains a trace of oxygen which is absorbed in tubes *B* and *C*, each containing an alkaline pyrogallol solution.

# PLATE VI




SPECTRUM OF HYDROGEN TUBES

A. With concave grating, iron comparison spectrum
B. With small prism, at different pressures

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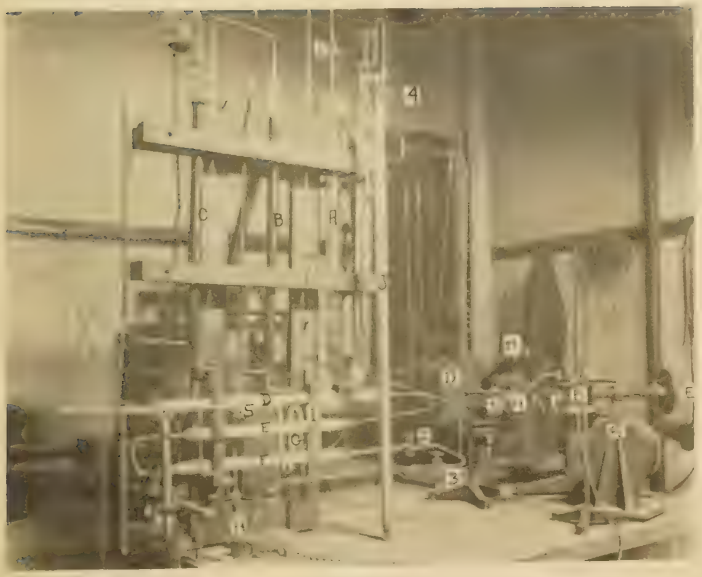


General View of Apparatus

The formula due to Hempel was used, as this seems to be one of the few satisfactory solutions for completely taking up oxygen without giving off carbon monoxide. It consists of 15 gms pyrogallol in

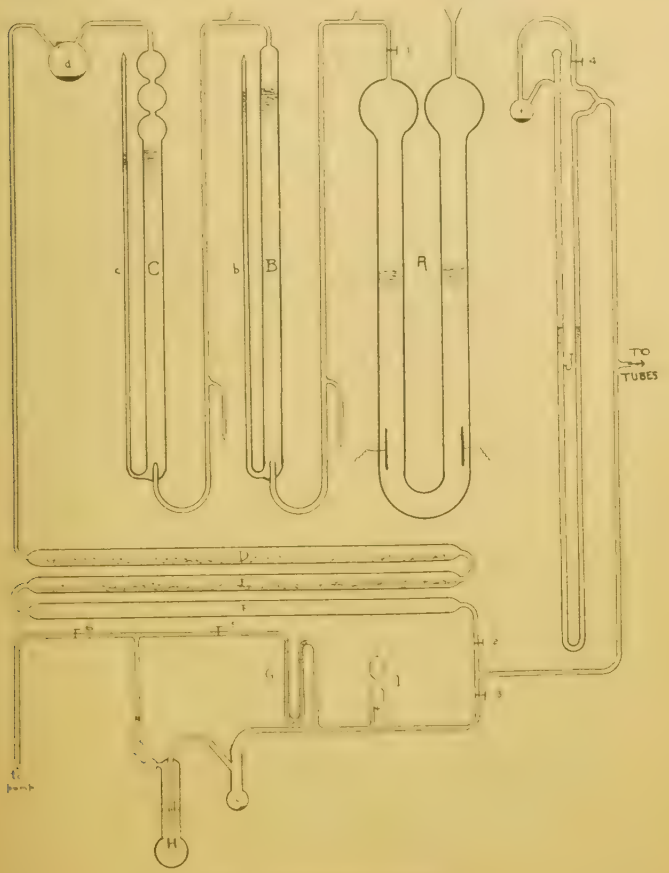


FIG. 1.—Hydrogen Generator

45 cc water; 360 gms potassium hydrate (prepared without use of alcohol) in 240 cc water. These two solutions are made separately, then thoroughly mixed, and quickly transferred to the tubes

prepared for them without any of the solution which entered the tubes having come in contact with the air. A very brief exposure to air will oxidize the solution and render it almost worthless. To avoid the presence of air in the apparatus at the start it was all completely exhausted before any of the liquids were admitted to it. The side tubes *b* and *c* make it possible to replenish the solutions when exhausted without contamination of the contained gas and without using stopcocks. The hydrogen, when thus freed from oxygen was collected in the tubes *D*, *E*, and *F*, which contained, respectively, calcium chloride, potassium hydrate sticks, and phosphorous pentoxide, and which serve as driers and as a storage chamber.

The stopcock 2 admits the gas to the experimental tubes which are in connection with a self-exhausting sulphuric acid manometer, *J*. When cock 4 in the manometer is open both sides can be completely exhausted, after which the cock is closed. On readmitting gas the difference in level assumed by the two arms indicates the pressure. The trap *f* serves to protect the cock from acid accidentally thrown over by the use of too high a pressure. Exhausting the apparatus takes place through cock 3 by means of a Gaede pump. To prevent diffusion of mercury vapor back from the pump into the discharge tubes two mercury traps, *G* and *H*, were provided. For all pressures down to .03–.04 cm cock 5 was left closed and the trap *H* used. This consisted simply of a tube just dipping beneath the surface of sulphuric acid. Exhaustion through this could take place down to a pressure approximately represented by the amount of submersion of the tube. For pressures below this amount cock 5 was opened and exhaustion took place through tube *G*, which was closely packed with gold leaf. At the low pressures for which *G* was needed the free path of the mercury molecules was large enough to prevent their diffusion through the spaces between the gold without hitting it. Thus all are caught and held by the latter. Obviously at higher pressures this might not be the case. These two traps were completely successful in preventing the diffusion of mercury back into the apparatus. During a year's intermittent use the test discharge tube at *I* never showed any trace of the mercury spectrum.

Fig. 2 shows a general plan of the rest of the apparatus. The light from the discharge tube, *D*, was compared with that from a Nernst glower, *N*, by a modified form of a Brace spectrophotometer, *B*. The selective absorption of the silver strip through the middle of the photometer prism was found to be negligible for such measures as these experiments involved. Constant slit-widths were used in both collimators, but the beam coming from the Nernst was plane polarized by means of a Nicol at *P*. After having traversed

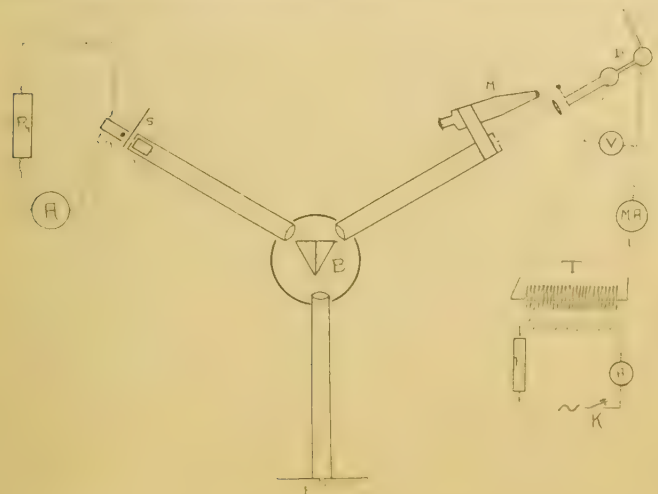


FIG. 2.—General Plan of Apparatus

identical paths through the prism (except for the reflection) the two beams unite in the telescope and the two spectra formed superimpose when viewed with an eyepiece at *E*. An eye-slit at this point cuts out all light except that of the spectral line or group being measured, and the background behind it. On removing the eyepiece and looking through the eye-slit with the eye approximately in the principal focus of the telescope lens the surface of the prism appears illuminated uniformly, except for the silver strip, which is of different intensity from the rest. Now by means of an analyzing Nicol in front of the eye the intensity over the rest of

the surface can be made to match exactly that of the silver strip, when, by careful adjustments, the latter disappears. The speed and accuracy of the settings obtainable with this form of spectrophotometer are too well known to require mention.

The Nernst comparison lamp, $N$, was a seasoned 90 v., 0.5 amp. glower held by means of a series resistance, $R_1$ at a constant current. A heavy metal shutter, $S$, screened the collimator slit from the intense radiation except while settings were actually being made. The discharge tubes had the form shown in section in Fig. 3. The

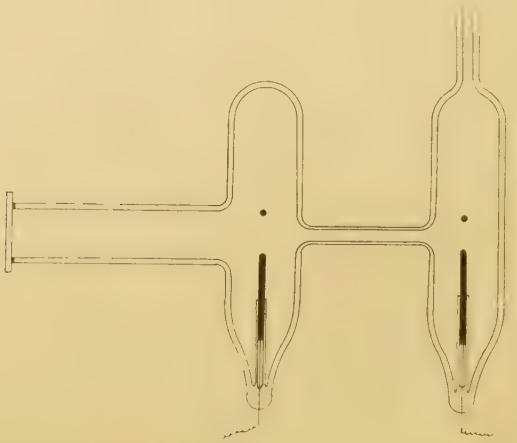

FIG. 3.—Discharge Tube

top part of the electrodes was bent into the form of a ring so that the light from the capillary could be viewed "end-on" through the side arm, which was closed with a quartz or glass window. The tubes were excited by means of the secondary circuit of a 5 kw. transformer (see Fig. 2). This circuit also contained as indicated a Weston milliammeter and a Brown electrostatic voltmeter. The primary of the transformer was fed through a series resistance, $R$, with alternating current from a 5 H.P. twin motor-generator set which had separately excited generator fields and could be held very constant. In fact, the current through the tubes never fluctuated by amounts readable on the milliammeter. An open

circuit program of observations was adopted, the switch $K$ being open and no current flowing through the tubes except at the moments settings were being made. Thus there was no heating of the tubes due to the discharge.

Several of the tubes were held simultaneously in a double-walled container which permitted the part containing the discharge to be entirely surrounded with liquid air when desired. The side arm of the tube, projecting through the walls of the container, gave an uninterrupted view into the interior of the tube at all times. On the window was attached by means of hard wax a fine needle point which was observed in a micrometer microscope, $M$, clamped to one of the collimators. Any shift between collimator and tube was, therefore, easily detected and carefully corrected by means of adjusting screws. Moreover, the various tubes in the container could thus be successively brought into alignment, moved out, and brought back again accurately to their original positions. Reliable measures were found impossible without this arrangement, since the changes in temperature to which the container was subjected would warp it slightly, thus bringing into view light from a slightly different portion of the capillary and causing thereby variations of selective intensity considerably larger than those due to the causes under consideration.

*Method of observation.*—The plan of observation finally adopted as the most reliable was to make at a given pressure two successive comparisons of the radiation of the discharge tube at room temperature with that of the Nernst glower. Then after cooling the tube two successive comparisons were again made with the glower, the gas density in the tube being kept the same and the electrical conditions remaining constant throughout. Fresh, spectroscopically pure gas was readmitted for every set of observations. The gas density was controlled in two ways: (1) Gas was admitted to the tube at the desired pressure and at room temperature, and the tube then sealed off from the rest of the apparatus. Observations were then made first at room temperature then at that of liquid air. Owing to the possibility that occlusion at the low temperature might change the gas density, only few observations were made using this method. (2) In most of the observations gas was

admitted to the tubes to the desired pressure and observations with the tube at room temperature taken. The tube was then cooled while remaining in connection with pump and gas supply and the pressure now so adjusted that the gas density was just the same as before, i.e., the pressure was made proportional to the absolute temperature. Observations at the low temperature were then made. No difference was observed in measurements resulting from these two different methods of control, except at very low pressures.

The current through the tubes being kept constant and the mass of gas between the electrodes being always the same, the potential difference between the electrodes would not be expected to change. Earhart[1] has shown, however, that the behavior of hydrogen is irregular in this respect, a fact which has been also observed in these experiments. For pressures below 6–7 mm the potential difference across the electrodes rises somewhat when the tube is cooled. At pressures above this value it falls somewhat on cooling. Test experiments have shown, however, that these variations are wholly incapable of producing in the radiation from the tubes such large changes as have been observed.

To sum up then: Under electrical conditions which have been controlled as closely as the nature of the case permits, indeed to within a few per cent, measurement has been made of the effect of a decrease in the temperature of the discharge tube from about 300° absolute to about 100° absolute, upon the photometric intensities of those parts of the hydrogen spectrum above mentioned, i.e., the series lines, $\alpha, \beta, \gamma$ ($\lambda = .656, .486, .434\mu$), the secondary groups, $a$, and $b$ ($\lambda = .601, .493\mu$ approx.), and the continuous ground immediately adjacent to $\alpha$, $\beta$, and $\gamma$, which is very near also to $a$, and $b$. The readings actually taken are successively on the intensities of (1) $\alpha+a_g$; (2) $a_g$; (3) $a+a_g$; (4) $b+\beta_g$; (5) $\beta_g$; (6) $\beta+\beta_g$; (7) $\gamma_g$; (8) $\gamma+\gamma_g$. The subtraction of (2) from (1) and (3), of (5) from (4) and (6), and of (7) from (8) give the true values of $\alpha$, $\beta$, $\gamma$, $a$, and $b$ corrected for background. (2) has always been observed equal to zero and therefore has been omitted from the tables.

[1] "The Effect of Temperature on Electrical Discharge in Gases," *Physical Review*, **31**, 652, 1910.

*Results.*—A summary of the results obtained is given below. Three different tubes were used which differed in general dimensions and especially in the bore of the capillary. Under a total current of 6 m.a. the different sized capillaries resulted in the following current-densities for the different tubes:

| | |
|---|---|
| Tube 1. | 2.3 amp/cm² |
| Tube 0. | 0.2 " |
| Tube 2. | 0.04 " |

Five different pressures were used, viz., 0.08, .13, .31, .70, 1.37 cm (*Hg*) respectively. The figures tabulated are the ratio

Intensity at T = 100°: Intensity at T = 300°.

Two independent measures of the numerator and two of the denominator were made. The four possible combinations of these which give the ratio are shown, as illustrating the experimental error, and the average taken. The total number of settings involved in the data of each table is given with it.

TABLE II

A

Pressure, 0.08 cm — Tube 2

Current-Density, 0.04 amp/cm² — 140 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .51 | .55 | .40 | 1.55 | 1.64 | 1.17 | 1.35 |
| .49 | .56 | .38 | 1.60 | 1.47 | 1.22 | 1.24 |
| .55 | .50 | .52 | 1.41 | 1.70 | 1.33 | 1.27 |
| .53 | .51 | .49 | 1.45 | 1.52 | 1.38 | 1.17 |
| Av. .52 | .53 | .45 | 1.50 | 1.58 | 1.27 | 1.26 |

B

Pressure, 0.08 cm — Tube 1

Current-Density, 2.3 amp/cm² — 105 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .58 | .31 | .30 | 1.22 | 1.24 | 1.13 | 1.27 |
| | | | 1.33 | 1.28 | 1.13 | 1.24 |
| Av. .58 | .31 | .30 | 1.27 | 1.26 | 1.13 | 1.25 |

TABLE III

A

Pressure, 0.18 cm — Tube 2

Current-Density, 0.04 amp/cm² — 210 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .64 | .52 | .64 | 1.36 | 1.21 | 1.30 | 1.28 |
| 61 | .62 | .57 | 1.41 | 1.31 | 1.28 | 1.28 |
| 53 | .54 | .53 | 1.36 | 1.08 | 1.19 | 1.23 |
| 51 | .63 | .57 | 1.41 | 1.17 | 1.17 | 1.23 |
| (.48 | .40 | .87 | 1.40 | 1.02 | 1.28 | 1.19) |
| Av. .56 | .56 | .58 | 1.38 | 1.18 | 1.24 | 1.24 |

B

Pressure, 0.18 cm — Tube 1

Current-Density, 2.3 amp/cm² — 140 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .28 | .28 | .33 | 1.18 | 1.54 | 1.57 | 1.38 |
| .28 | .33 | .34 | 1.30 | 1.47 | 1.57 | 1.77 |
| .32 | .30 | .40 | 1.09 | 1.63 | .... | |
| .32 | .26 | .41 | 1.20 | 1.56 | .... | |
| Av. .30 | .32 | .37 | 1.19 | 1.55 | 1.57 | 1.57 |

TABLE IV

A

Pressure, 0.32 cm — Tube 2

Current-Density, 0.04 amp/cm² — 280 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .51 | .56 | ... | 2.00 | 1.85 | 1.59 | 1.40 |
| .52 | .56 | ... | 2.00 | 2.16 | 1.40 | 1.47 |
| .42 | .50 | ... | 1.57 | 1.78 | 1.08 | 1.40 |
| .43 | .50 | ... | 1.58 | 2.08 | 1.48 | 1.47 |
| Av. .47 | .53 | ... | 1.78 | 1.97 | 1.54 | 1.44 |

B

Pressure, 0.32 cm — Tube 1

Current-Density, 2.3 amp/cm² — 140 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .37 | .52 | .45 | 1.12 | 1.30 | 1.00 | 0.92 |
| .36 | .49 | .37 | 1.12 | 1.30 | 1.00 | 0.92 |
| .38 | .53 | .44 | 1.00 | 1.38 | 0.95 | 1.03 |
| .37 | .50 | .35 | 1.00 | 1.38 | 0.95 | 1.03 |
| Av. .37 | .51 | .40 | 1.06 | 1.34 | 0.97 | 0.97 |

C

PRESSURE, 0.32 CM — TUBE 0

Current-Density, 0.2 amp/cm² — 140 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .64 | .74 | ... | 1.51 | 1.55 | 1.49 | 1.11 |
| .64 | .79 | ... | 1.41 | 1.52 | 1.29 | 1.21 |
| .67 | .59 | ... | 1.45 | 1.52 | 1.43 | 1.07 |
| .67 | .63 | ... | 1.33 | 1.30 | 1.27 | 1.17 |
| Av. .66 | .69 | ... | 1.42 | 1.42 | 1.36 | 1.14 |

TABLE V

A

PRESSURE, 0.7 CM — TUBE 2

Current-Density, 0.04 amp/cm² — 210 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .62 | .47 | ... | 2.47 | 1.78 | 1.33 | 1.42 |
| .62 | ... | ... | 2.56 | .... | 1.25 | 1.37 |
| .67 | .83 | ... | 2.44 | 1.99 | 1.34 | 1.42 |
| .66 | ... | ... | 2.52 | .... | 1.26 | 1.37 |
| .60 | .87 | ... | 2.37 | 1.73 | 1.32 | 1.42 |
| .59 | ... | ... | 2.46 | .... | 1.24 | 1.37 |
| Av. .63 | .71 | ... | 2.47 | 1.83 | 1.29 | 1.40 |

B

PRESSURE, 0.7 CM — TUBE 1

Current-Density, 2.3 amp/cm² — 70 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .45 | .38 | .60 | 1.93 | 1.84 | 1.94 | 2.10 |
| .31 | .43 | .55 | 1.86 | 1.95 | 1.56 | 1.96 |
| Av. .38 | .40 | .58 | 1.90 | 1.90 | 1.75 | 2.03 |

TABLE VI

A

PRESSURE, 1.37 CM — TUBE 2

Current-Density, 0.04 amp/cm² — 140 Settings

| $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|
| .47 | .23 | ... | 2.38 | 2.44 | 1.25 | 1.02 |
| .50 | .34 | ... | 2.24 | .... | 1.00 | 0.98 |
| .31 | .45 | ... | 1.94 | 1.69 | 1.20 | 0.97 |
| .33 | .66 | ... | 1.82 | .... | 0.96 | 0.94 |
| Av. .40 | .40 | ... | 2.10 | 2.06 | 1.10 | 0.97 |

TABLE VII

SUMMARY

Current-Density, 0.04 amp/cm² Tube 2

| Press. | $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|---|
| .08 cm | .6 | .5 | .4 | 1.5 | 1.6 | 1.3 | 1.3 |
| .18 " | .6 | .6 | .6 | 1.4 | 1.2 | 1.2 | 1.2 |
| .31 " | .5 | .5 | .. | 1.8 | 2.0 | 1.5 | 1.4 |
| .70 " | .6 | .7 | .. | 2.5 | 1.8 | 1.3 | 1.4 |
| 1.37 " | .4 | .4 | .. | 2.1 | 2.1 | 1.1 | 1.0 |

Current-Density, 2.3 amp/cm² Tube 1

| Press. | $\alpha$ | $\beta$ | $\gamma$ | $a$ | $b$ | $\beta_g$ | $\gamma_g$ |
|---|---|---|---|---|---|---|---|
| .08 cm | .6 | .3 | .4 | 1.3 | 1.3 | 1.1 | 1.1 |
| .18 " | .3 | .3 | .4 | 1.2 | 1.5 | 1.6 | 1.6 |
| .31 " | .4 | .5 | .4 | 1.1 | 1.3 | 1.0 | 1.0 |
| .70 " | .4 | .4 | .5 | 1.9 | 1.9 | 1.8 | 2.0 |

It is seen from these tables, summed up in Table VII, that the results, for all pressures and the two widely different values of current-density used, are in quite good agreement. In all cases at the lower temperature, the series spectrum weakens to about 0.5 its normal value, and the compound line spectrum strengthens to 1.5 or 2.0 times its normal value, while the continuous background increases somewhat, but less than the compound spectrum. Inasmuch as the background consists of true continuous spectrum plus some faint compound spectrum, it is quite possible that the true background changes little if at all, the faint compound spectrum mixed with it being responsible for the slight rise shown.

The radiant energy, then, as the discharge tube is cooled, tends to leave the series lines and to go into the compound line spectrum. This is in accord with the general behavior of series and many-lined spectra. The former are characteristic of substances which radiate at temperatures considerably above their melting or boiling points or under the most powerful electrical conditions; the latter are characteristic of substances such as iron, titanium, etc., whose condition when radiating approaches the solid or liquid state. Continuous spectra are characteristic of glowing solids and liquids. Hydrogen exhibits simultaneously these three kinds of spectra.